Theological Reflections on Chaos Theory

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This paper reviews the historical origins of chaos theory and some of its key features, and then reflects theologically on the implications of this theory for a Christian view of the world. It is argued that chaos theory does not represent a threat to Christian faith, but in fact provides new ways of understanding the richness and complexity of God's creative work and providential ordering of the physical universe.

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"We collectively wish to apologize for having misled the general educated public by spreading ideas about the determinism of systems satisfying Newton's laws of motion that, after 1960, were proved to be incorrect." Professor James Lighthill, then president of the International Union of Theoretical and Applied Mechanics, made this remarkable public apology exactly three hundred years after Newton's great *Principia Mathematica* was presented to the Royal Society of London. "Modern theories of dynamical systems," Lighthill went on to say, "have clearly demonstrated the unexpected fact that systems governed by the equations of Newtonian dynamics do not necessarily exhibit the `predictability' property."[1]

In his presidential address, Dr. Lighthill was reflecting on a new field of scientific research that has come to be known as *chaos theory*‹a body of theoretical concepts and experimental results that has changed the way scientists think about determinism, predictability, and a broad variety of phenomena in the natural world ranging from the weather to the beating of the human heart to the growth and decline of animal populations.

It is the purpose of this paper to review the historical origins of chaos theory and some of its key features, and then to reflect theologically on its implications for a Christian view of the world. Does chaos theory provide new perspectives on the vexing question of determinism and free will, as some commentators have suggested? If chaos research has undermined the predictable, "clockwork" universe of Newtonian science, what implications does this have for our understanding of the limitations of human knowledge and man's control of nature? Does chaos theory open up new ways to understand the relationship of "chance" events to the providence of God, and the ways in which God creates new forms of life in the natural world? These are some of the questions that call for theological reflection. The general conviction that forms the basis of this paper is that not only does chaos theory *not* represent a threat to Christian faith, but it, in fact, provides new ways of understanding the richness and complexity of God's creative work and providential ordering of the physical universe.

Chaos Theory: Historical Origins and Key Features

In 1963 Edward Lorenz, a meteorologist at the Massachusetts Institute of Technology, published an article, "Deterministic Nonperiodic Flow," which was destined to become a classic in the newly emerging field of chaos research.[2] Using mathematical models and computer simulations of flow patterns in the atmosphere, Lorenz concluded that for weather forecasting, "...prediction of the sufficiently distant future is impossible by any method." In view of the inevitable incompleteness of weather observations, "...precise very-long-range weather forecasting would seem to be non-existent."[3] As Lorenz's results became known, most scientists came to agree that earlier optimism about human ability to control the weather or even forecast it in the longer term was scientifically unfounded. Systems like global weather were simply too complex to admit of long-range predictability.

Lorenz's studies of weather forecasting gave rise to a concept in chaos research that is popularly known as the "Butterfly effect." The rather remarkable idea expressed in this term is that a very small change in the initial conditions of some physical system‹e.g., the fluttering of a butterfly's wing in Peking, as it cascades unpredictably through a complicated system‹can have very large effects later in time, e.g., producing a thunderstorm in New York. The "Butterfly effect" is a striking metaphorical expression of a general characteristic of chaotic systems that is more abstractly characterized as "sensitive dependence on initial conditions." If one were able to balance a pencil on its point, it is obvious that the slightest touch in any direction would produce a much larger effect‹the fall of the pencil to the surface. This is a very simple and crude illustration of a feature‹*sensitive dependence on initial conditions*‹that applies to a great variety of complex systems in the physical world: the flow of gases and liquids through the atmosphere or through pipes, the behavior of certain chemical solutions; electronic circuits, human heartbeats; the spread of diseases through a population, the dripping of water droplets from a faucet, the formation of patterns and fractures in metallic and crystalline surfaces, the formation of snowflakes, the behavior of the stock market, and so on. In each of these cases, and many more like them, very small changes in the system at the beginning can be multiplied so as to produce erratic and unpredictable behavior at some later point in time. Even the swinging of a pendulum‹long thought to be the

paradigm of Newtonian predictability‹is now known to exhibit "chaotic" and irregular motion under certain conditions.[4]

Chaotic behavior is associated with systems that are termed "dissipative" by physicists, that is, systems where friction is a significant factor. Water flowing through a pipe or a hockey puck moving across the ice are examples of such "dissipative" systems. In such cases a *nonlinear equation* is needed to describe the behavior of the system. In contrast to linear equations‹represented by a straight line on a graph‹nonlinear equations are very difficult to solve, and in many cases have no exact solutions. Such equations are "messy," and as a result mathematicians and physicists have tended to give them less attention until relatively recently. The recent research in chaos theory that began emerging in the 1960s established the remarkable result that systems described by such nonlinear equations, while in principle being deterministic and obeying the laws of classical Newtonian physics, are characterized by long-term unpredictability. One researcher in this field, David Ruelle, has suggested that the essence of chaotic systems is the paradoxical combination of "determinism‹yet long-term unpredictability."[5] The surprising thing is, as James Crutchfield has noted, that "simple deterministic systems with only a few elements"‹such as a swinging pendulum‹"can generate random behavior." This randomness is fundamental, observes Crutchfield; "gathering more information does not make it go away."[6]

In 1975, the biologist Robert May published an important article in the journal *Nature* in which the concepts of chaos theory were applied to the growth of animal populations.[7] May demonstrated that a relatively simple equation of the form X[next] = kX(1-x), used to model the growth and decline of an animal population in a given environment, could display very erratic and unpredictable behavior over time. May's application of chaos theory to biological and ecological systems challenged biologists to look at population growth in a different way. Traditionally, biologists had tended to assume that erratic fluctuations in, say, the number of deer in a certain habitat simply reflected fluctuations in the environment such as drought or disease. May's analysis demonstrated that such fluctuations could be "built in" to the very mathematical laws that described population growth. In his seminal article May also drew attention to the fact that traditional scientific textbooks focused on the simple systems that had predictable behaviors. Consequently, students were poorly equipped to confront the *nonlinear* and "chaotic" systems that were so common in the real world outside the laboratory. "Not only in research, but also in the everyday world of politics and economics," May observed, "we would all be better off if more people realized that simple nonlinear systems do not necessarily possess simple dynamical properties."[8] May was, in effect, calling for a "paradigm shift" in biology that would recognize and take seriously a body of unpredictable behavior that had been there all along. The fact that May was trained in theoretical physics and applied mathematics before becoming involved in biology "through the back door"[9] was symptomatic of the frequently cross-disciplinary interests of many workers in this new field‹quite in contrast to the dominant trend toward narrow specialization that had come to dominate science since the nineteenth century.

During the 1960s and 1970s new developments in chemistry, thermodynamics [the study of heat] and pure mathematics contributed significantly to the newly emerging field of chaos research. In 1977 the Belgian scientist Ilya Prigogine was awarded the Nobel prize for his work in *non-equilibrium thermodynamics*. Classical thermodynamics, developed in the nineteenth century, studied the flow of heat in systems that were tending toward thermal equilibrium: if the door between one room with air at 80 degrees and an adjoining room with air at 60 degrees is opened, over time the air temperature will tend toward an equilibrium temperature of 70 degrees. Prigogine discovered that chemical solutions and heated fluids could also display both oscillations and erratic, unpredictable behaviors, quite unlike the phenomena studied in traditional chemistry and thermodynamics. Prigogine also argued that in many cases these nonlinear, chaotic systems could give rise to order and new complexity at higher levels in the system, and so also might provide a way of understanding the emergence of life itself from its chemical and physical substrates.[10]

New developments in pure mathematics also spurred the development of chaos research. In the 1970s Bernard Mandelbrot, a somewhat eccentric mathematician working in IBM's pure research division in New York, pioneered a whole new field of mathematics which came to be known as *fractal geometry*.[11] Mandelbrot coined the term "fractal" to describe the irregular, jagged patterns that could describe an astonishing variety of forms in nature: snowflakes, clouds, a flash of lightning, the coastline of Britain, fractures in metal, or the crust of the earth. Traditional Euclidean geometry had predisposed the human eye to see nature in terms of straight lines and smooth curves; Mandelbrot had provided a new geometrical "lens" that could help man to see nature in all its rough complexity. Mandelbrot had provided scientists and engineers with a powerful new mathematical tool to study the rough and jagged surfaces of metals, the tiny holes and channels in oil-bearing rocks, the intricate network of capillaries in the human body, to only mention a few of the many applications the new geometry in the physical and life sciences.

Some have raised the question of why "chaos" was not discovered sooner, given the fact that many of the phenomena‹e.g., the possibly erratic motions of a simple pendulum‹were, in principle, known long before the new field emerged in the 1970s. Very early in the twentieth century, for example, the great French mathematician Poincare had pointed to the "chaotic" possibilities lurking in the equations of Newtonian science.[12]Part of the answer may lie in the fact that not until the 1960s did scientists have at their disposal as research tools the powerful computers that could perform the laborious "number crunching" involved in solving the nonlinear equations used to model chaotic behaviors. For much of the twentieth century, the energy and attention of physicists were absorbed in exploring the new vistas opened by quantum theory and special relativity. And until Mandelbrot and other mathematicians developed new mathematical tools for conceptualizing and rigorously describing these irregular and erratic phenomena, scientists tended not to "see" realities that had been there all along.

The Reality of Chaos: Theological Reflections

At the time of this writing there has been only limited response from the theological

community to the new discoveries in chaos research. This, however, is not surprising, given the rather technical nature of much of this work and the recency of these developments. The first international scientific conference on chaos theory was held in 1977 in Como, Italy, and many of the most significant of the original scientific papers are hidden away in obscure journals not easily accessible to the general public.

As early as the 1950s, however, some Christian theologians were giving attention to the issues of chance and unpredictability in relationship to God's providential government of the world. As we shall see below, these reflections do have relevance to the issues later raised by chaos research. These early reflections were in large measure attempts to come to grips theologically and philosophically with the issues raised by the strange and unpredictable phenomena of quantum physics, which began to penetrate the public consciousness in the 1920s. In his 1958 book *Chance and Providence*, the priest-physicist William Pollard stated that the Christian could answer "Yes" to Einstein's famous question, "Does God throw dice?" According to Pollard, "...only in a world in which the laws of nature govern events in accordance with the casting of dice [i.e., probability] can the biblical view of a world whose history is responsive to God's will prevail."[13] For Pollard biblical and scientific descriptions of the same events were complementary, and "chance" was encompassed within the divine providence.

Similarly, Donald M. MacKay, writing in 1978, defined "chance" as "what defies determination on the basis of precedent." Chance refers to events that may be *unforeseeable*, but they are not therefore *meaningless*. From a Christian perspective, apparently chance events are subsumed under the wider providence of God.[14] Both Pollard and MacKay were dealing with "quantum" uncertainties rather than "chaotic" uncertainties, but their observations do have analogical relevance to the newly discovered unpredictable phenomena that burst upon the scientific world subsequent to their writings.

In his 1979 article, "God and the Contingent Order," the Scottish theologian Thomas F. Torrance reflects on the new awareness of *temporality* and *irreversibility* in science, alluding to Big Bang cosmologies and the non-equilibrium thermodynamics of Ilya Prigogine. Torrance writes at a time when an initial awareness of chaos research is beginning to extend beyond the boundaries of the scientific community, and attempts to incorporate these new perspectives into Christian understandings of God's relationship to the world.[15]

The 1984 book by the statistician D. J. Bartholemew, *God of Chance*, is one of the most significant recent attempts to relate the reality of chance in the natural world to a Christian understanding of providence. Thinking primarily of quantum uncertainties, but with some awareness of the newer chaos theory, Bartholemew believes that "...since chance is such an integral part of creation, it must be part of God's plan." Chance should be seen as "...grist for the providential mill rather than as an obstacle to providential action." Chance can, in fact, play a very positive role in God's creative work, since the variety and uncertainty which it introduces provide a stimulating and challenging environment for the full scope of human development.[16] Like Pollard and MacKay before

him, Bartholemew sees chance and unpredictability as consistent with, rather than antithetical to, the providential purposes of God.

Writing in the 1980s and early 1990s, Philip Hefner and Stuart Chandler discussed the notion of chaos in ancient religious mythologies, but with little or no interaction with recent scientific research in chaos theory.[17] In his 1989 article, the British meteorologist J. T. Houghton suggests that chaos theory represents a significant challenge to reductionistic views of the world, and believes that nature uses chaos constructively to provide biological systems with access to new forms of novelty.[18]

In August of 1993 a cross-disciplinary group of twenty scholars and scientists met at the Center for Theology and the Natural Sciences in Berkeley, California to explore the implications of chaos theory for philosophical and theological understandings of God's action in the world. The conference papers, representing both scientific and theological perspectives, were subsequently published under the title *Chaos and Complexity: Scientific Perspectives on Divine Action*.[19] This volume represents the most substantial philosophical and theological response to date to chaos theory. Most of the contributors, however, concluded that chaos theory did not provide any easy answers to the question of exactly how God's action in the world was to be understood in relationship to scientific laws.

Chaos Theory: Further Theological Reflections

Some writers have suggested that chaos theory provides a way of resolving the vexing problem of *determinism and free will.* If the behavior of matter is determined by physical laws, and human beings (including their brains) are at least in part material beings, how can the exercise of free will be consistent with these physical laws? James Crutchfield has suggested that inasmuch as underlying chaotic processes selectively magnify small fluctuations, "... chaos provides a mechanism that allows for free will within a world governed by deterministic laws."[20] In a similar vein, Doyne Farmer, a scientist then working at the Los Alamos National Laboratory, observed that chaos theory might provide "an operational way to define free will," a way to reconcile free will and determinism. "The system is deterministic, but you can't say [exactly] what it is going to do next."[21]

However attractive those suggestions might initially appear to be, further reflection reveals them to be seriously problematic. The basic problem is that these suggestions are essentially *reductionistic*, in that they attempt to explain a human and personal reality (freedom) in terms of entities that are impersonal and sub-personal. As such, this approach makes a fundamental category mistake: physical realities can be explained by appealing to physical substances and laws, but personal realities refer to a higher dimension of reality‹the personal‹that subsists within the natural order, but at the same time transcends it. Such a standpoint is indicated by the biblical conception of man as being both "dust"‹and so part of the natural order ‹and "image of God"‹and so transcending the natural order. The biblical doctrine of the *imago Dei* places a fundamental barrier (from a Christian viewpoint) against all attempts to explain the human person completely or exclusively in terms of scientific laws. The suggestions

noted above, while well intended, have the irremediable defect of reducing a human and spiritual reality to a phenomena explainable by the behavior of material objects and forces.

There is yet another sense in which the suggestions of Crutchfield and Farmer represent serious category mistakes. In attempting to find a "space" for human freedom in a deterministic world, there is an implicit identification of "freedom" with "randomness" or "unpredictability." The problem with this implicit identification is that it overlooks the crucial fact that genuine human freedom is connected with the *purposes* of human agents acting for the realization of certain ends. I choose a certain career or to marry or not to marry in light of my values and purposes. Genuinely free choices of human agents take place within this purposive or *teleological* context. The point being made here can perhaps be clarified by noting that it makes no sense to say that a spinning roulette wheel is exercising "free will" simply because its behavior appears to be random and unpredictable. The appearance of randomness or unpredictability may be associated with a free choice, but such randomness is not of the essence of freedom. The purposive dimension of human choices, directed toward the realization of certain ends among a number of alternatives, cannot be reduced to the categories of physics‹whether or not the physics in question is Newtonian, quantum-mechanical, or "chaotic."

A substantial consensus has emerged among scientists, philosophers, and theologians that the new discoveries in chaos research have shattered forever the Newtonian image of a predictable "clockwork universe" that has dominated the popular imagination for the last three hundred years. It is now known that for these chaotic systems, while in principle governed by laws that are still deterministic in form, small uncertainties are amplified so radically that in practice, as Robert J. Russell has noted, "their behavior rapidly becomes unpredictable."[22] Arthur Peacocke, a trained biochemist and Anglican priest, has emphasized that such unpredictability is "ineradicable" and is not removable by even an "absolutely accurate knowledge of the initial conditions, if this were attainable."[23]

In chaotic systems there is an inescapable "predictability horizon" (e.g., for the weather, about two weeks) beyond which exact prediction is impossible. "We are able to come to this conclusion without ever having to mention quantum mechanics or Heisenberg's uncertainty principle," notes James Lighthill. "A fundamental uncertainty about the future is there, indeed, even on the supposedly solid basis of the good old laws of motion of Newton."[24]

These startling new scientific perspectives are just beginning to penetrate the general public's consciousness, but informed scientists realize that the Enlightenment dream of a thoroughly predictable and controllable world is now dead and in the process of being buried. This dream was given classic expression in a famous series of lectures given in 1795 at the Ecoles Normales in Paris by the great French mathematician Pierre-Simon Laplace, an apostle of the Newtonian world system. Imagine, said Laplace, that we could look at the world, with all its objects, planets, and individual atoms, from the perspective of an infinite intelligence, having a comprehensive knowledge of all the initial positions and velocities. "We ought then to consider the present state of the universe as the effect

of its previous state and as the cause of that which is to follow," wrote Laplace, expressing the determinism of physical law. "For such an [unlimited] intelligence nothing would be uncertain, and the future, like the past, would be open to its eyes."[25] In this Laplacean "clockwork" universe an "infinite intelligence"‹or quasi-omniscient scientist‹could presumably predict the headlines appearing on tomorrow's *New York Times*!

This Laplacean dream has been shattered forever; scientists now realize that indeed it was never true. Ironically, it is now apparent that even that paradigm of regularity and predictability‹the simple pendulum‹can exhibit chaotic behavior under certain conditions. And astonishingly, it has been recently recognized as well that the *solar system*, long considered to be the model of regularity, exhibits chaotic behavior as well. The motion of the planet Pluto is chaotic, and the orbits of Venus and the Earth exhibit substantial irregularities. The known instabilities in the orbit of Mercury are such that this planet can probably cross the orbit of Venus within five billion years. According to the French astronomer Jacques Laskar, "Without the Moon, the tilt of the Earth would be highly unstable, which would probably have strongly disturbed the development of organized life on its surface." The rotation of the planet Mars on its axis is chaotic, and can "wobble" between 0 and 60 degrees![26]

In reality the larger universe is not a simple, linear Newtonian mechanical system; in many respects it behaves as a chaotic system. "No finite intelligence, however powerful," physicist Paul Davies has concluded, "could anticipate what new forms or systems may come to exist in the future."[27]
This "death of the dream of unlimited predictability" points to fundamental *limitations on human knowledge* that scientists have encountered during the last century. Einstein's Special Theory of Relativity stated that the speed of light placed an absolute limit on the speed of travel of any physical object or message. Heisenberg's Uncertainty Principle indicated fundamental limitations on human ability to measure quantities in the sub-atomic world. The Second Law of Thermodynamics pointed to inherent limitations on the efficiency of heat devices and the impossibility of ever constructing a "perpetual motion" machine. Now chaos theory has demonstrated the inherent limitations on human ability to predict and control the future. From a Christian perspective, such an encounter with the limits inherent in the nature of the physical realm should remind man of the fundamental distinction between an *infinite Creator* and a *finite and limited creation, including man.* The new discoveries of chaos theory give man further reason to adopt a stance of "epistemic humility" in the face of a complex and unpredictable world.

Chaos theory also has important philosophical implications for the *reductionism* implicit in much of the modern scientific agenda. Now that it is increasingly being realized that even simple systems can give rise to complex and unpredictable behavior, more scientists are beginning to acknowledge that the entire range of physical and personal reality cannot be adequately explained in terms of the motions and interactions of atoms, molecules, and elementary particles. These scientists have begun to see the limitations of studying parts in isolation from the whole. "For them," notes James Gleick, "chaos was the end of the reductionist program in science."[28]

James Crutchfield has concluded that the hope that physics could offer a complete description of physical reality through an increasingly detailed understanding of fundamental particles and forces is unfounded. The fact is that the interaction of components on one scale ".. can lead to complex global behavior on a larger scale that in general cannot be deduced from knowledge of the individual components."[29] Paul Davies says flatly that " reductionism is nothing more than a vague promise founded on the Š discredited concept of determinism."[30]

This growing recognition of the inadequacy of reductionism as a master paradigm for science implies that the realities of living organisms, including man, cannot be exhaustively understood in terms of the categories of physics and chemistry. Living beings subsist within the material order, of course, and are subject to and, to a considerable extent, analyzable in terms of material categories. But these physical and chemical processes give rise to new levels of organization, complexity, sentience, and value that transcend the purely physical, and which should be accorded "ontic recognition" together with the elementary particles of physics.

It should again be stated that what is *not* being claimed here is that one can draw a straight logical inference from chaos theory to, say, human freedom. To attempt to do so would be to fall back into the same reductionistic approach that is being criticized, i.e., the notion that at the end of the day human freedom is really "nothing but" the product of the motion of material particles. What is being suggested here is rather that the new perspectives arising from chaos research help to make "cultural and epistemic space" for the human sciences, including religion. Any scientific work that highlights the untenable nature of the Enlightenment and Laplacean vision is, at least indirectly, a significant contribution to a more adequate worldview that acknowledges the complex, multi-leveled, and less predictable nature of the world that God has created. If science now acknowledges the impossibility of predicting the future behavior of even a simple *pendulum* in all cases, then how much more should it be seen to be impossible to reduce *human behavior and values* to nothing more than the motion of material particles. To the extent that chaos research provides a check against the "epistemic hubris" of a Laplacean agenda for science, then a new sensibility is made possible and a new cultural space can arise for more fruitful interactions between the natural sciences and religious communities.

Chaos theory also provides new perspectives for understanding God's works of *creation* and *providence***.** In particular, these new discoveries make it possible to see some of the issues in the historic creation-evolution controversies in a different light. As a case in point, it is well known that in his 1874 attack on Darwinism, the Princeton theologian Charles Hodge saw the fundamental threat to Christian faith to be the denial of purpose and design in nature. "The denial of final causes is the formative idea of Darwin's theory," Hodge believed, "and therefore no teleologist can be a Darwinian." In Hodge's view, the denial of design in nature was tantamount to a denial of God. Darwin was personally not an atheist, but his theory was "virtually atheistical." God may have called the universe into existence, and created the first germ of life; but afterward "abandoned the universe itself to be controlled by chance and necessity, without any purpose on his

part as to the result." It was this denial of divine providence, as Hodge understood Darwin's theory of evolution, which led Hodge to finally conclude, as the answer to the question posed in the title of his book: "What is Darwinism? It is atheism."[31]

In Hodge's view, Darwinism was completely incompatible with Christian theism because "pure chance" was inconsistent with divine providence. The new perspectives provided by chaos research have opened up other ways of understanding the relationship between "chance" events and lawlike behaviors. As Bartholemew and others have pointed out, it is now recognized that apparently random behaviors can lead to orderly results; order can be a consequence of "chaos." For example, the behavior of any given individual and their age of death are highly uncertain, but the actuarial tables of life insurance companies can give very accurate forecasts of mortality for the population at large. Bartholemew has drawn attention to the very significant fact that "the mere existence of chance processes in nature is not a sufficient ground for inferring the absence of purpose."[32] Just as human agents can use chance mechanisms for their own purposes‹in a lottery, in a game of Monopoly, or to distribute a limited number of kidney dialysis machines‹so it is certainly possible to conceive of God using apparently random processes to achieve his own creative purposes.

Writing from this perspective, Arthur Peacocke has argued that the new discoveries of chaos and complexity have suggested a new paradigm for understanding nature in terms of the *creative interplay of chance and law.* Chance operates within a lawlike framework which limits the possible outcomes. Chance allows for new forms of life and organization to emerge, while deterministic laws provide the stability for these new forms to endure. "It is the combination of the two [law and chance] which makes possible an ordered universe capable of developing within itself new modes of existence."[33] In this perspective, chance is not an autonomous metaphysical principle opposed to divine purpose, but is part of a larger lawful structure and one of the mechanisms used by God in the process of creation. Viewed in this light, the role of chance in evolutionary theory is not necessarily a threat to Christian theism as Hodge supposed.[34]

This way of viewing the relationship of chance events to the providence of God has significant precedent in the history of Christian theology. In *Summa Contra Gentiles*, Thomas Aquinas states that while all events are subject to divine providence, not all "Šwill be necessary, but a good many are contingent." God is the cause of all things, and just as an animal cares for its young, so God takes care of all that he has made. His divine providence applies to contingent singulars such as the fall of a sparrow (Matt. 10:29) as well as to those things that happen by necessity.[35]

In chapter five, paragraph two of the Westminster Confession of Faith (1647)‹perhaps the single, most influential confessional document in English-speaking Christianity‹the issue of providence is addressed. The Westminster divines, speaking from a Puritan and Calvinistic theological perspective, stated that "Although in relation to the foreknowledge and decree of God, the first cause, all things come to pass immutably and infallibly, yet by the same providence he ordereth them to fall out, according to the nature of second causes, either necessarily, freely, or contingently." The confession here uses the

Thomistic distinction between *primary* and *secondary* causes. God is the primary and ultimate cause of all that happens, whether the fall of a sparrow, the fall of an empire, the rising of the sun, or the crucifixion of the Messiah. God's primary causation is usually mediated, however, through the agency of secondary causes‹either through human choices or through the operation of natural laws. These secondary causes can act "necessarily," as in the falling of a stone to the ground; "contingently," as in the casting of a lot; or "freely," as in King David's decision to commit adultery with Bathsheba. Though the seventeenth century worldview of the Westminster divines understood the term "contingently" in terms of what we would now call "classical uncertainty" (i.e., a "coin toss") rather than "quantum" or "chaotic" uncertainty, which were unknown at the time, it is nevertheless the case that their basic standpoint can be extended to encompass the new phenomena of chaos theory. "Secondary causes" can be expanded to include the phenomena described by quantum mechanics and chaos theory as well as those described by Newtonian (or Aristotelian) physics. All events of history and nature are embedded within a lawful, coherent structure ultimately ordered by the providence of God.

It is also important to note that the biblical understanding of the relationship of God to chaotic phenomena is quite different from that found in many cosmologies of the ancient world. In a creation myth from the ancient Near East such as the *Enuma Elish*, the so-called "Babylonian Genesis," Marduk battles for supremacy among the gods by defeating Tiamat, the personification of the forces of chaos.[36] In Plato's *Timaeus*, the Demiurge gives form to a pre-existing chaotic matter rather than calling all things into being by a sovereign act of *ex nihilo* creation.[37] In biblical thought, the chaotic forces of nature and history are not divine beings or metaphysical principles that have independence over against God. The God of the Bible is the sovereign Creator, Sustainer, and Redeemer who uses the humanly unpredictable and controllable forces of the natural world for his own purposes.

In a textbook on chaos theory written for scientists and engineers, Francis C. Moon notes that the new paradigm which is beginning to supplant the Newtonian "clockwork" image embodies a "Š concept of chaotic events resulting from orderly laws, not a formless chaos, but one in which there are underlying patterns, fractal structures, governed by a new mathematical view of our `orderly' world."[38] Moon's observation that chaotic phenomena are embedded in deeper underlying structures accords remarkably well with a biblical theology of creation and providence. There is a "logos structure" (John 1:1,3; cf. Col. 1:1520) in God's created order which encompasses the turbulent and unpredictable events studied by the chaos theorists. These phenomena are "chaotic" but do not represent a "lawless" or "unbounded" chaos; they are embedded within deeper structures of order.

In one of the closing chapters of the book of Job, God speaks to Job out of the whirlwind and asks: "Where were you when I laid the earth's foundations?" (Job 38:4). In a long series of questions about the creation, God leads Job to realize that a deeper awareness of the features of the natural order can be a cause for wonder and humility in the face of God's creative work. Recently Ilya Prigogine has written, "Everywhere we look, we find a nature that is rich in diversity and innovations."[39] The new discoveries of chaos theory represent one of the more recent and exciting chapters in the history of mankind's

encounters with God's creation. Far from being a threat to a biblical understanding of providence, chaos theory can be seen as a new avenue for appreciating both the limitations of human ability to predict the future and the complexity and richness of God's creative power.

Notes

[1]James Lighthill, "The Recently Recognized Failure of Predictability in Newtonian Dynamics," *Proceedings of the Royal Society of London* A 407 (1986): 35-50 at 38, 35.
[2] Edward N. Lorenz, "Deterministic Nonperiodic Flow," *Journal of the Atmospheric Sciences* 20 (1963): 13041. Lorenz's work is discussed in James Gleick, *Chaos: Making a New Science* (London: Abacus, 1993; 1987), 1131. Gleick's work is one of the most readable popular presentations of chaos theory currently available.
[3]Lorenz, op. cit., 141.
[4]Lighthill, op. cit., 427.
[5]David Ruelle, *Chance and Chaos* (London: Penguin Books, 1993), 45.
[6]James Crutchfield, et. al., "Chaos," *Scientific American* 255:6 (December 1986): 3849 at 38. This article is a good introduction to chaos theory for the general reader. Other introductions that use little mathematics include William Ditto and Louis Pecora, "Mastering Chaos," *Scientific American* 269:2 (August 1993): 62-83; Ian Stewart, *Does God Play Dice? The Mathematics of Chaos* (Oxford: Basil Blackwell, 1989), especially chapters 511; J T. Houghton, "New Ideas of Chaos in Physics," *Science & Christian Belief* 1 (1989): 4151; Paul Davies, *The Cosmic Blueprint* (London: Unwin Hyman, 1989), chapter 4, 3556, "Chaos." Technical treatments for scientists and engineers include A. J. Lichtenberg and M. A. Lieberman, *Regular and Stochastic Motion* (New York: Springer-Verlag, 1983), especially chapter seven, "Dissipative Systems"; M. V. Berry, et. al., "Dynamical Chaos," *Proceedings of the Royal Society* A 413 (1987): 1199; Jong Hyun Kim and John Stringer, eds., *Applied Chaos* (New York: John Wiley & Sons, 1992).
[7]Robert M. May, "Simple Mathematical Models with Very Complicated Dynamics," *Nature* 261 (1976): 45967.
[8]Ibid., 467.
[9]Gleick, op. cit., 69.
[10] *Dialogue with Nature* (New York: Bantam, 1984). Prigogine believes that the new discoveries in non-equilibrium thermodynamics, which emphasize the importance of time and irreversible events in nature, can provide a new paradigm that can reunite the physical, biological, and human sciences, often seen as fundamentally bifurcated since the time of Newton.
[11]The seminal work here is Bernard Mandelbrot, *The Fractal Geometry of Nature* (New York: Freeman, 1977).
[12]In 1903 Poincare had written, "Šit may happen that small differences in the initial conditions produce great ones in the final phenomena. A small error in the

former will produce an enormous error in the latter. Prediction becomes impossible, and we have the fortuitous phenomenon." Cited in Crutchfield, op. cit., 40.
[13]William G. Pollard, *Chance and Providence: God's Action in a World Governed by Scientific Law* (London: Faber and Faber, 1958), 97.
[14]Donald M. MacKay, *Science, Chance, and Providence* (Oxford: Oxford University Press, 1978), 39. Compare the similar viewpoint of Peter Geach, *Providence and Evil* (Cambridge: Cambridge University Press, 1977), 116: "Chance" events may not be determined by humanly knowable causes, but they do not "Šescape from the knowledge and control of Divine Providence," citing Prov. 16:33. Geach also observes on p. 120 that "If men are to act freely there must be both some determinism [law, regularity, predictability] and some indeterminism [unpredictability] in the world." An "Alice in Wonderland" world in which pink-flamingo croquet rackets were not dependably rigid would be chaotic; a "clockwork" world of iron-clad determinism would be boring, oppressive, and destructive of genuine human freedom and moral responsibility.
[15]T. F. Torrance, "God and the Contingent World," *Zygon* 14:4 (1979): 32948.
[16]D. J. Bartholemew, *God of Chance* (London: SCM Press, 1984), 118, 138, 143.
[17]Philip Hefner, "God and Chaos: the Demiurge versus the *Urgrund*," *Zygon* 19:4 (1984): 46985, contrasting the negative role of chaos in Plato's *Timaeus* and the Babylonian *Enuma Elish* with the creative role of chaos in the philosophy of N. Berdyaev; Stuart Chandler, "When the World Falls Apart: Methodology for Employing Chaos and Emptiness as Theological Constructs," *Harvard Theological Review* 85 (1992):46791, discussing chaos in religious mythology and "emptiness" in the Buddhist tradition. J W. Stines, in "Time, Chaos Theory and the Thought of Michael Polanyi," *Perspectives on Science and Christian Faith* 44 (1992): 2207, attempts to relate chaos theory to the notion of "tacit knowledge" in the philosophy of Michael Polanyi, but apparently does not clearly see chaotic uncertainty as a new *tertium quid* distinct from *quantum* uncertainty and the "classical" uncertainty [e.g., a coin toss] of Newtonian physics.
[18]J. T. Houghton, "New Ideas of Chaos in Physics," *Science and Christian Belief* 1 (1989): 4151.
[19]Robert John Russell, Nancey Murphy, and Arthur R. Peacocke, eds., *Chaos and Complexity: Scientific Perspectives on Divine Action* (Vatican City: Vatican Observatory Publications, 1995).
[20]Crutchfield, op. cit., 49.
[21]Quoted in Gleick, op. cit., 251.
[22]Russell, op. cit., 14.
[23]Arthur Peacocke, *Theology for a Scientific Age* (London: SCM Press, 1993), 51.
[24]Lighthill, op. cit., 47.
[25]Pierre-Simon Laplace, *Philosophical Essay on Probabilities*. Translated from the 5th French edition of 1825 by Andrew I. Dole (New York: Springer-Verlag, 1995), 2.
[26]The astronomical data cited in this paragraph is from Jacques Laskar, "Large-Scale Chaos in the Solar System and Planetological Consequences," paper

summary in *Sciences de la Terre et des Planetes* (Paris) Tome 322, Series IIa, No. 3, item 163.
[27]Davies, *The Cosmic Blueprint* (London: Unwin Hyman, 1989), 56.
[28]Gleick, op. cit., 304.
[29]Crutchfield, op. cit., 48; see also Houghton, op. cit., 50.
[30]Davies, op. cit., 140. Davies does not claim that "reductionistic" techniques in science are never justified, only that reductionism is not adequate as a global scientific paradigm or metaphysical framework.
[31]Charles Hodge, *What Is Darwinism?* (New York: Scribner, Armstrong and Co., 1874), 1737.
[32]Bartholemew, op. cit., 78, 82.
[33]Peacocke, *Theology for a Scientific Age*, 65. Similarly, Prigogine has argued as one of the main conclusions of his research that "Š nonequilibrium is the source of order," op. cit., 287.
[34]Hodge was, of course, correct in seeing an *autonomous* "blind chance," understood as an independent metaphysical principle, to be incompatible with Christian theism. Hodge no doubt would have reached similar conclusions with respect to modern anti-teleological presentations of evolutionary theory such as Jacques Monod, *Chance and Necessity* (London: Collins, 1972); Richard Dawkins, *The Blind Watchmaker* (Harlow, UK: Longman, 1986), and Stephen J. Gould, *Wonderful Life* (New York: Norton, 1989). The point being made here is that placing chance and chaos within the larger law structures created by God gives an entirely different perspective for understanding the issues of the creation-evolution debate. The "random variations" of evolutionary biology are then seen as the providential means ordained of God in the process of creation. For the variety of Christian responses to Darwinian evolution in the nineteenth century, see James R. Moore, *The Post-Darwinian Controversies* (Cambridge: Cambridge University Press, 1979).
[35]Thomas Aquinas, *Summa Contra Gentiles*. Book Three: *Providence*, Part I, chapters 72, 74; tr. Vernon J. Bourke (Notre Dame, IN: University of Notre Dame Press, 1975), 2424; 2503.
[36]For translation and commentary on the *Enuma Elish*, see Alexander Heidel, T*he Babylonian Genesis: The Story of Creation* (Chicago: University of Chicago Press, 1951), and Stephanie Dalley, *Myths from Mesopotamia: Creation, The Flood, Gilgamesh, and Others* (New York: Oxford University Press, 1989). For illuminating discussion of the Genesis creation narrative in the context of ancient Near Eastern religions, see Claus Westermann, *Genesis 1-11: A Commentary*, tr. John J. Scullion (London: SPCK, 1984), "Creation in the History of Religions and in the Bible," 1947.
[37]Timaeus 30a, in *Plato,* v. IX, tr. R. G. Bury (Cambridge, MA: Harvard University Press, 1929), 55.
[38]Francis C. Moon, *Chaotic and Fractal Dynamics: an Introduction for Applied Scientists and Engineers* (New York: John Wiley & Sons, 1992), 42, 43.
[39]Prigogine, op. cit., 208.